

Partial English Translation of
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JAPANESE PATENT APPLICATION
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[0006] to [0008], [0016] to [0021] and [0041]

[0006] The object of the present invention is to provide a high performance semiconductor light-emitting device and a fabrication method thereof which are achieved by taking into consideration of a buffer layer which reduces the strain caused by the difference of thermal expansion coefficient. In such a semiconductor light-emitting device, no cracking easily occurs in a GaN semiconductor on a sapphire substrate and a silicon-carbide (SiC) substrate, whereby fabrication yield is high and crystallinity is excellent.

[0007]

[Means of Solving the Problems] To attain the above object, the following means are taken in the present invention.

[0008] As a first means, an $\text{Al}_x\text{Ga}_{1-x}\text{N}$ buffer layer ($0.10 \leq x \leq 0.14$) is used in crystal growth of the GaN semiconductor on the sapphire substrate. In this association, the lattice constant of GaN at room temperature in the state where the compressive strain is received from the sapphire substrate is close to that of the AlGa_xN buffer layer. Therefore, it is possible to form a semiconductor layer with less strain, less dislocation and excellent crystallinity. This effect is remarkable particularly when a composition ratio x of Al is 0.12 since the strain can be reduced to the maximum extent.

[0016] (Embodiment 1) In GaN crystal formed on a sapphire substrate, dislocation and cracking easily occur. "Japanese Journal of Applied Physics" explains the reason therefor as follows on pp. 1528-1533, Vol. 32 (1993): A lattice mismatch rate of GaN to sapphire is approximately 16 % and the rate of the thermal expansion coefficient difference therefrom is

approximately 130 % (Figure 1). Therefore, when GaN is grown on the sapphire substrate, misfit dislocation occurs due to the lattice mismatch in the vicinity of a substrate interface at the crystal growth and the misfit dislocation is propagated to the surface of the GaN due to the thermal expansion coefficient difference in a cooling process after the crystal growth, thereby resulting in breakthrough dislocation and cracking caused (Figure 2). As a result, dislocation occurs in the GaN layer with a high density of approximately $10^{10}/\text{cm}^2$ level.

[0017] Figure 3 shows respective relationships between lattice constants and temperatures (from room temperature to a growth temperature) of GaN, sapphire and GaN crystals formed on the sapphire substrate.

[0018] In Figure 3, the respective inclinations of the straight lines indicate respective thermal expansion coefficients. Since the thermal expansion coefficient of sapphire is larger than that of GaN by approximately 130 %, the GaN crystals on the sapphire substrate receive compressive stress in the cooling process after the growth. This compressive strain is estimated at approximately $3.5 \times 10^9 \text{ dyn/cm}^2$ at room temperature, and therefore, the lattice constant of the GaN crystals on the sapphire substrate is smaller than its inherent lattice constant, as indicated by a point A in Figure 3. In this case, a GaN semiconductor that matches with this lattice constant (point A) at room temperature is $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ($0.10 \leq x \leq 0.14$) and application of this semiconductor to the buffer layer makes it possible to reduce the strain to be approximately one fourth (10^8 dyn/cm^2 level) of that in the conventional device. Particularly when the composition ratio x of Al is 0.12, such effect is remarkably exhibited. More specifically, it is possible to reduce the strain to one fiftieth ($8 \times 10^7 \text{ dyn/cm}^2$) of that in the conventional device, and hence, it is possible to remarkably suppress occurrence of cracking and breakthrough dislocation which are caused by the strain.

[0019] The crystal growth of GaN is performed, using Metalorganic Vapor Phase Epitaxy (MOVPE). Before the growth, the sapphire substrate is organic-cleaned with ultrasonic wave. Next, the substrate is disposed on a susceptor in a reactor of a MOVPE system. Subsequently, after air discharge for evacuation is performed, the substrate is heated for 15 minutes at approximately 1100°C in a hydrogen atmosphere of 70 Torr

and the surface of the substrate is cleaned.

[0020] When GaN is grown on the sapphire substrate, after the temperature is set down to approximately 500 °C first of all, trimethyl-gallium (TMG) of 2 μ mol/minute, ammonia of 2.5 L/minute and carrier hydrogen of 2 L/minute are supplied, so that a low temperature GaN buffer layer having a thickness of approximately 30 nm is grown. Next, the GaN layer is grown at a temperature of approximately 1000 °C. Moreover, When the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer ($0.10 \leq x \leq 0.14$) according to the present invention is grown on the sapphire substrate, the low temperature GaN buffer layer (30 nm) and the GaN buffer layer (500 nm) are grown, and then, trimethyl-aluminium (TMA) of 10 μ mol /minute is also flown so that the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ layer having a thickness of approximately 2 μ m is grown at a temperature of approximately 1000 °C.

[0021] It is actually found that application of the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ ($x=0.12$) layer to the buffer layer makes it possible to suppress remarkably occurrence of the cracking and to reduce the dislocation density to be approximately $10^7/\text{cm}^2$ level. Therefore, it is possible to achieve a high performance the GaN semiconductor, less strain and less dislocation density on the sapphire substrate by the fabrication method using the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ buffer layer.

[0041]

[Effect of the Invention] As is explained above, according to the first fabrication method of the present invention, it is possible to fabricate the high performance GaN semiconductor in which the dislocation density and the strain are respectively reduced to be approximately one hundredth (10^7 cm^{-2}) and one fiftieth ($8 \times 10^7 \text{ dyn/cm}^2$) of those of a conventional device since it is possible to reduce the strain caused due to the thermal expansion coefficient difference between the sapphire substrate and GaN by using the $\text{Al}_x\text{Ga}_{1-x}\text{N}$ buffer layer ($0.10 \leq x \leq 0.14$) on the sapphire substrate, to suppress increase in breaking dislocation. Further, no cracking occurs on the surface of the crystals and the fabrication yield can be remarkably increased. Particularly when the composition ratio x of Al is 0.12, the effect is remarkable since the strain can be reduce to the maximum extent.